Electrons energy distribution in helium plasma, generated by fission fragments

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Abstract. The problem of ionization and excitation pair prices in any gas medium can be solved by modeling the process of exchanging energy of the primary electrons with neutrals by Monte Carlo technique. The advantage of this method is that the physical processes of individual collisions of electrons are associated with a direct statistical analogy – branching random walk of a particle in a one–dimensional phase space. In this case, the transition probabilities are determined by the relevant integral cross sections of the processes of electron interactions with neutrals. This method allows a more complete analysis of the process, calculating as an average values of the characteristics of the interaction, and the time evolution of the electrons energy distribution.
Key words: Monte Carlo method, energy distribution, excites atoms, electron ionization, cross section.

Introduction

The Monte Carlo method is characterized by the large value of computer time expenditure. However, due to the following outstanding works [1, 2, 3, 4, 5] we have produced some "simplification". For example, to play high–energy electrons in the evolution of the energetic field as a model of continuous deceleration in the threshold region we were able to implement direct modeling – a method called "enlarged collision" [6]. One of the main advantages of the Monte Carlo method is that all the characteristics of interaction – the number of ionization and excitation spectra of electrons of different generations, etc. are analyzed directly in the modeling process, and not defined in terms of range degradation, which makes them more reliable. Finally, and most important for the numerical calculation of the energy spectrum of electrons in gases – the correct selection of cross sections of elementary processes of interaction of electrons with atoms and molecules of the medium, which primarily determine the electron spectrum in the energy range near the threshold [7]. The calculation code was compiled on the time depending processing circuit branching process for generations. After each act of ionization electron traced with more energy, and the energy of secondary electrons born are also randomly played and memorized in all of an electronic memory. Subsequently primary simulated electron energy was taken randomly from primary electron energy distribution [7]. Tracking the trajectories of the primary electron energy was carried out up to 0.1 eV. The time dependence of electron energy distribution in nuclear excited helium plasma is found and analyzed in the present paper.

Electrons energy distribution in helium plasma

Primary electrons

Taking into the consideration that fast protons and tritons colliding with neutrals interact through a Coulomb field we use results obtained by Michal Gryzinski [12].The products of the reaction (1) $^3He + n \rightarrow {}^3H + p + 0.76Mev$ will meet helium neutrals but interact with orbital electrons exciting and ionizing helium atoms. The ionization rate is defined by the density of thermal neutrons and by the energetic electron and ion pair formation price Ω and equals:

$$S = \frac{n(\,^3He)*\Phi*\sigma_f*E_0}{\Omega}, \quad (11)$$

where n(^{3}He) – concentration of helium atoms, Φ – neutron flux, σ_f – cross section of nuclear reaction (3.1), E_0 –kinetic energy of fission fragments. To evaluate the energy distribution of primary electrons ionized by the reaction (1) products we should calculate the following

$$f_{pe}(t,r,E) = \int_{24.59}^{192*10^3} \left[n(\,^3He)\Phi(t,r) * \sigma f Eneutrons E0\ protons \Omega*(E,T) dT, \right. \quad (12)$$

where t – time, r – electron density coordinate, E – electrons energy.

$$\sum(E,T) = f_v * \frac{\sigma_0}{(T-I_p-E)^3}\left[\frac{V_p^2}{V_p^2+V_e^2}\frac{(T-I_p-E)}{\frac{m_e V_e^2}{2}} + Ln(2.7+VpVe)1-(T-IHe-E\Delta\mathrm{Emax})1+VpVe, \right. \quad (13)$$

where T – energy of protons, I_p – ionization potential, V_p – protons velocity, V_e – electron velocity.

$$f_v = \left[\frac{V_e}{V_p}\right]^2 \left[\frac{V_p^2}{V_p^2+V_e^2}\right]^{\frac{3}{2}}. \quad (14)$$

$$\Delta E_{max} = \frac{m_e V_e^2}{2} * 4 * \left[1 + \frac{V_e}{V_p}\right]. \quad (15)$$

$$\sigma_0 = 6.56 * 10^{-14} eV^2 sm^2. \quad (16)$$

$$V_p = 2.1 * 10^6. \quad (17)$$

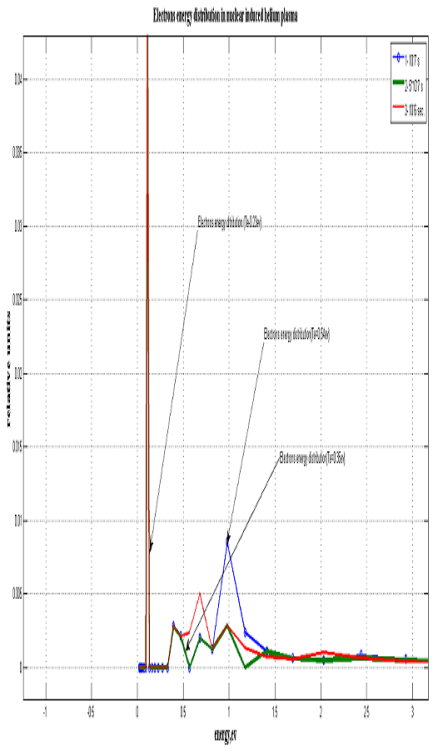

Figure 3 – Electrons energy distribution in nuclear induced helium plasma.

Excitation cross sections of helium atoms by fission fragments are evaluated by the following:

$$\sum_{p,T}(E) = f_v * \frac{\sigma_0}{(E-I_{excitation})^3}\left[\frac{V_{p,T}^2}{V_{p,T}^2+V_e^2}\frac{(I_{He})}{\frac{m_e V_e^2}{2}} + 231 - IexcitationΔEmaxLn(2.7+VpVe)1-(IexcitationΔEmax)1+VpVe, \quad (18)$$

where $I_{excitation}$ – excitation energy.

In the present paper we accept to study the following excited states of helium atoms with their corresponding energy levels: $1S^2S_0^1, 2^3S, 2^1S_0, 2^3P_0, 3^1S_0, 3^1P_1, 3^1D_2, 3^3S_1, 3^3P, 3^3D$ with energy levels as 19.82, 20.00, 20.03, 20.06, 20.09, 21.22, 21.39, 21.46, 21.40, 20.61, 20.85. The upper level $(4^1S_0, 4^1P_1, 4^1D_2, 4^3S_1, 4^3P_1, 4^3D, 4^3F)$ is taken as a common upper excited level.

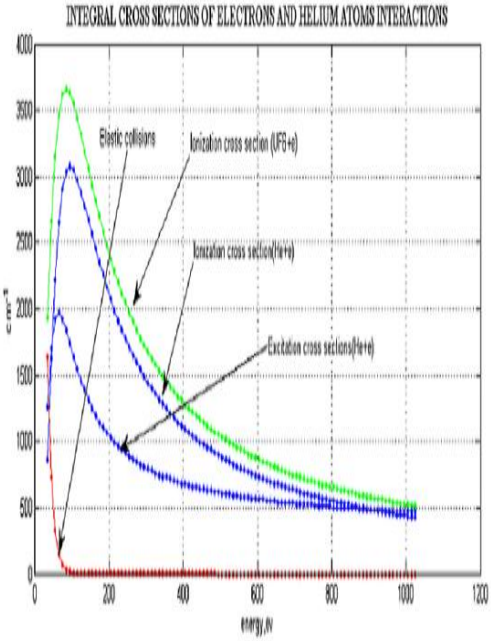

Figure 4 – Integral cross sections of electrons and helium atoms interactions.

Monte Carlo code description

The calculation program was built on the processing circuit branching process for generations. After each act of electron ionization traced with more energy, and the energy born of an electronic memory. Then there is the electron trajectories simulated future generations. Tracking the trajectory of the primary electron energy was carried out to 0.1 eV. N simulated particles with energy E_0 (mono–energetic source). If the electron energy E> E_{gr} = 20 eV, the electron mean free path was played by the formula:

$$t = ln\xi\lambda(E), \quad (19)$$

where ξ – uniformly distributed in the interval [0,1] random number, λ(E) – mean free path is equal to:

$$\lambda(E) = (\sum_1(E) + \sum_2(E) + \cdots + \sum_i(E))^{-1}, \quad (20)$$

where $\sum_i(E)$ – macroscopic scattering cross–section i–th channel. Then scattering channel was played by the formula:

$$\xi \leq \frac{\sum_1 + \sum_2 + \cdots + \sum_i}{\sum_1 + \sum_2 + \cdots + \sum_n}. \quad (21)$$

In the case of elastic scattering differential cross sections at the corner of the angle of the scattered electron was played out on the screened nucleus. The loss of energy in the elastic collision was calculated by the formula:

$$\Delta E = \left(\frac{2m}{M}\right) * (E - E_T) * (1 - cosv), \quad (22)$$

where m and M – the mass of the electron and the scattering center, E_T – the thermal energy of the target atom, v – scattering angle. In the case of ionization was assumed that the energy of the ejected electron shell with $E = E - E_b$ (E_b is the binding energy) is less than the energy of the scattered. Its coordinates, direction and energy are remembered for future follow–up. The energy of the secondary scattered electrons was played out from their cross section energy dependence distribution similarly as follows:

$$\xi = \frac{B_j E}{A_j + E^2} + C_j, \qquad (23)$$

where A_j, B_j, C_j – the parameters tabulated in [1]. This distribution exists on the base of an inverse transform which has the following form:

$$\Delta E = \sqrt{A\left[\left(\frac{E^2+A}{A}\right)^{\xi} - 1\right]}.$$

In case of loss of excitation energy of the incident electron is equal to the excitation threshold of the appropriate level. If the electron energy is becoming less E_b = 20 eV, the elastic scattering is taken into account only to the loss of energy by the formula (4.3.4). The new coordinates the interaction of the electron considered when calculating the electron mean free path t – by (4.3.1) and the cosine of the scattering angle $cosv$. For the three–dimensional coordinates (x_i, y_i, z_i) conversion formulas have the form:

$$x_{i+1} = x_i + tcosv_x,$$

$$y_{i+1} = y_i + tcosv_y,$$

$$z_{i+1} = z_i + tcosv_z \quad .$$

To calculate the electron distribution function is summed up time during which the electron and the secondary electrons generated by them $d\tau = \Sigma\tau^1$ in the interval $d\xi$. Number traces the history should not be much large, since proportionally increase the cost of computer time, but it should provide the statistical reliability of the calculated distributions.

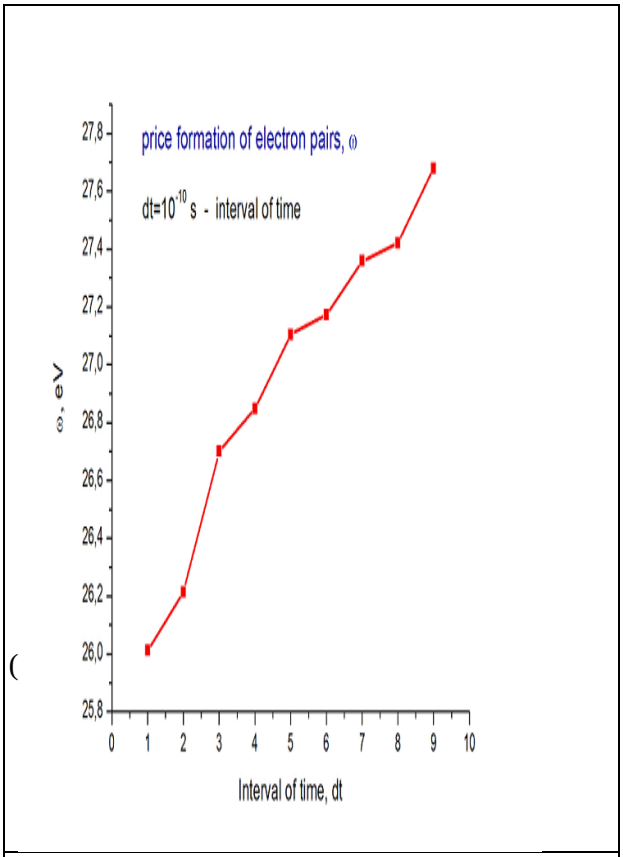

Figure 5 – Price formation of electron pairs.

Conclusion

Consider the nature of the formation of the energy distribution of electrons in the ionization of the gas by the electron beam. For a simple atomic gas, in this case helium, on the energy axis along which electrons degrade the resultant plasma, there are several gaps and corresponding electronic groups.

The first group includes the primary electrons that excite and ionize atoms and is relaxing rapidly within time about 10^{-9} sec. The electrons knocked out in the ionization of the secondary electrons with energy, higher threshold energy inelastic interactions are creating the second group – a group of electron ionization stage. Sub threshold electrons whose energy is much greater than the temperature of the gas form the third group. They are cooled mainly due to elastic collisions with gas. The fourth largest group of plasma electrons are cooled and bring the slow electrons with energies of the order of the gas temperature. These electrons form a Maxwell distribution and determine the flow of recombination [11]. Mathematical methods for solving problems on the energy distribution of electrons and the nature of the approximations in different energy groups are significantly different. Formation of the energy distribution of electrons in the energy range 0.1–1000 eV can be seen in the space–local approximation, since the mean free path of electrons is much smaller than the mean free path of electrons in the beam.

The calculations of the distribution function of the electron energy in the present work using the Monte Carlo method

show that the results of calculations

depend only on the set of cross sections and quantities used, which determines its reliability.

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